



Article

Multi-Scale Characterization of Unusual Green and Blue Pigments from the Pharaonic Town of Amara West, Nubia

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Abstract: Pigments from paint palettes and a grindstone excavated from the pharaonic town of Amara West (c. 1300–1050 BCE), which lies between the Second and Third Cataracts of the Nile, were examined using polarized light microscopy, attenuated total reflection Fourier transform infrared spectroscopy (ATR-FTIR), X-ray diffraction, and scanning electron microscopy with energy dispersive X-ray spectroscopy. Most of the pigments were consistent with the typical ancient Egyptian palette, but the greens and some blues were unusual. Two types of green pigment were identified, chlorite (varieties clinocllore and penninite) and copper chloride hydroxide (atacamite type). The former constitutes a type of green earth which has only rarely been identified in pharaonic Egyptian contexts and may be more widespread than is currently reported. The majority of the blue pigment samples were Egyptian blue, but some were found to be a blue earth, the main component of which being sodic amphibole riebeckite. The use of this mineral as a pigment has not previously been reported in any Nile Valley context. These results prompt questions around local and potentially indigenous practices within an ancient colonial context, and highlight avenues for future research.

Keywords: pigments; ancient Egypt; Nubia; Egyptian blue; atacamite; green earth; riebeckite



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1. Introduction

The analysis of pigments can reveal the material strategies being utilized by ancient populations, including the use of locally available pigments or those supplied or traded from elsewhere, and the societal frameworks that may restrict access to certain materials. This study was undertaken on a pharaonic site situated in occupied Nubia, geographically distant from the administrative centers of Egypt, and occupied by inhabitants who expressed, as preserved in the material record, a spectrum of cultural affiliations incorporating Egyptian, indigenous Nubian (which may well comprise a number of distinct groups), and hybrid formulations drawing on both. Can pigment analyses elucidate aspects of these cultural expressions and access to materials and technologies?

Studies of pigments from ancient Egypt have focused on elite and funerary contexts, such as tombs [1–5] and palace walls, or from museum objects (e.g., papyri, coffins) which have almost exclusively been collected from tombs or have unknown or uncertain provenance [6–8]. The analysis of the pigments found at Amarna [9–12] and Elephantine [13] provide rare evidence from settlements. The Egyptian Ministry of Tourism & Antiquities does not allow the export of samples for scientific analysis, which limits the scope of scientific studies on material found in fieldwork within the country, although some in situ studies have been possible [14,15]. Samples can be exported from Sudan with the generous permission of the National Corporation for Antiquities & Museums, facilitating a wider

range of analytical techniques. Recent fieldwork by the British Museum's Amara West Research Project provided an opportunity to analyze pigments from a range of late second millennium BC urban contexts, with the potential to provide insights into the materials used beyond the high elite contexts which characterize much of our knowledge about pigments in the ancient Nile Valley.

Amara West

Amara West was founded in the reign of Seti I (c. 1306–1290 BCE) between the 2nd and 3rd cataracts of the Nile, in what is now northern Sudan. The walled town (108 × 108 m, Figure 1) contained a stone cult temple, storage facilities, housing, and a formal residential building which housed the Deputy of Kush, the foremost pharaonic official in Upper Nubia [16]. In the decades after its foundation, many of the storage facilities were co-opted for additional housing, with further dwellings being built outside the town wall from around 1180 BCE, in an area designated by excavators as the Western Suburb. Throughout, one can trace individual and/or household agency in the repeated reshaping and remodelling of the urban fabric [16,17]. Ceramic evidence suggests the town was abandoned by 1000 BCE, perhaps prompted by an increasingly challenging environment created by a retraction of Nile channels [18], though activity can be traced in the cemetery through the 8th century BCE [19].

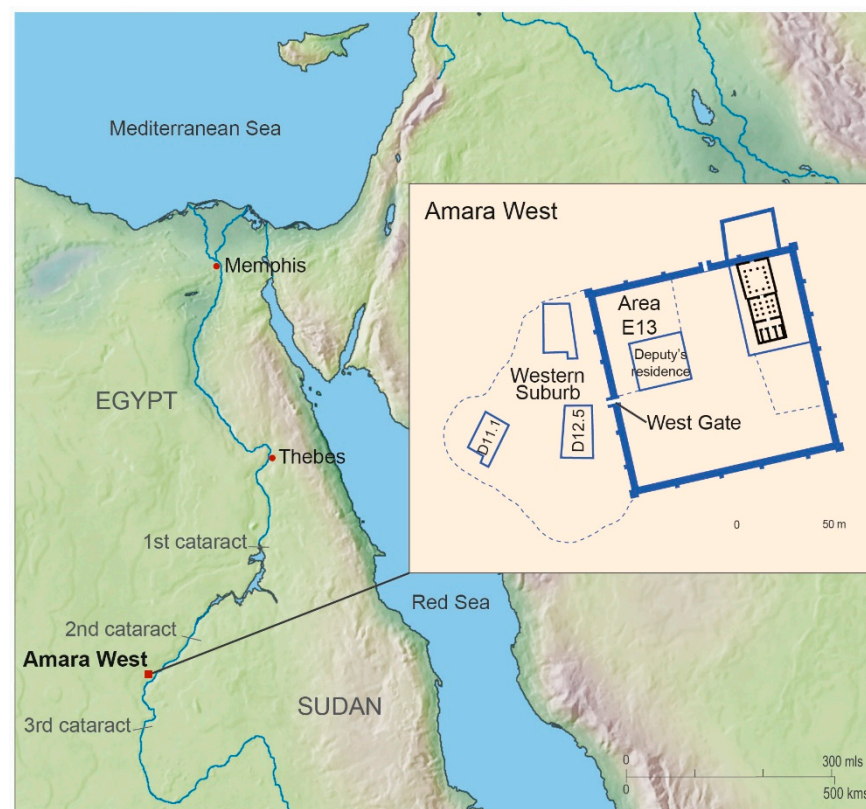


Figure 1. Location and layout of Amara West.

The first systematic excavations at Amara West, by the Egypt Exploration Society, took place between 1938 and 1950 [20]. More recent fieldwork at the site was undertaken by the British Museum from 2008 to 2016 [16,21]. All of the material discussed here comes from the latter excavations. A large number of the pigment-related finds in the walled town come from building E13.14, a facility north of the Deputy's Residence founded early in the town's history, comprising three long storage magazines with vaulted roofs, accessed via a service corridor. This building was later modified, with the north-eastern part being transformed into a workshop (E13.31), and the remainder was integrated into a large house (E13.7).

The eastern part of that house later became another workshop suite (E13.29) (Figure 2). Combined, these areas contained over 300 ceramic shards with pigment on their inner concave surfaces, likely to have been used as palettes for preparing paint ahead of application, and many small lumps of raw pigment. Workshop E13.31 also contained two large grinding stones used for pigments, small copper alloy objects, pieces of crucible, ostrich eggshells, faience beads, small flint blades, and worked stone. Immediately to the north of E13.31 was an area (E13.17) perhaps associated with metalworking which preserved further concentrations of pigments and palettes in occupational deposits, amidst a typical array of other finds (stone tools, ceramic counters etc.). Another, smaller, concentration of palettes and pigments was found in space E13.20, and the underlying area E13.22, which are contemporaneous with E13.29 and E13.31. With a limited exposure, the character of E13.20 and E13.22 is unclear, though a series of curved walls may have defined an exterior space associated with houses. In contrast to these concentrations of color-related finds in the walled town, the Western Suburb yielded less material, though clusters of pigment lumps and palettes were found in houses D11.1, D12.8, and D12.9.

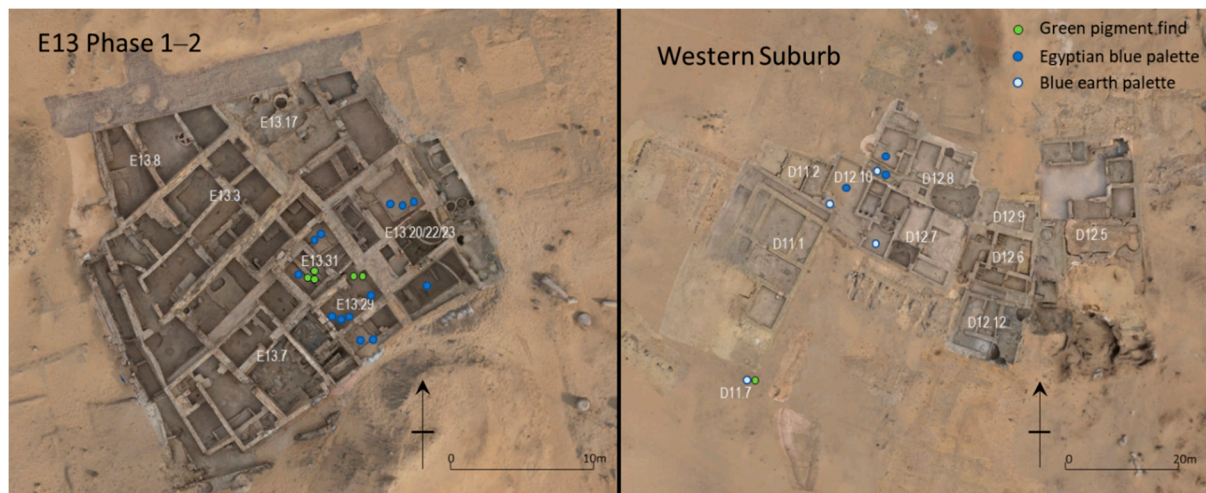


Figure 2. Locations of blue and green samples mentioned in the text in the walled town E13 (**left**), and the Western Suburb (**right**). The green pigment (PS506) from grindstone F6184 and in the pile on the floor next to the grindstone (PS118) pre-date workshop E13.31 (**left**). One Egyptian blue palette was excavated from room E13.6.4, which is Phase 3 and therefore not shown on this map; it overlies workshop E13.31 (**left**).

A full study of the paints used at Amara West was conducted as an Arts and Humanities Research Council (UK) funded PhD [22]. White gypsum and calcite, yellow ochre, and red ochre were the most commonly used pigments, but there was also evidence for black soot and ground bitumen [23], as well as blue and green pigments. The pigments, grinding stones, and ceramic palettes are likely to have been used for the application of paint in various contexts. Firstly, the sandstone temple reliefs would have been brightly painted in this full range of colors; gilding was also noted by the EES excavators [20] (pp. 27–52). Secondly, the West Gate of the town, with reliefs depicting battle scenes, was also brightly painted [16] (p. 327). Thirdly, a restrained use of paint was deployed in the houses through whitewashed walls, framing lines in black and, in a limited number of houses, colorfully painted wall shrines evoking temple architecture [17]. Fourthly, micromorphological analysis of sedimentary deposits revealed the preparation of red slurries, mostly derived from crushed rocks available locally, to use in ritual and/or prophylactic practices within the houses [24]. Finally, a number of wooden grave goods, particularly coffins, were painted, with the notable addition of huntite as a white pigment [21,22].

2. Materials and Methods

2.1. Sampling from Site

Twenty-one palettes containing blue pigment were found during the British Museum fieldwork at Amara West. Seventeen contained a bright blue pigment (Figure 3a), fourteen of which were from E13, and three of which were from the Western Suburb (Figure 2). Four palettes from the Western Suburb contained a greyish-blue pigment (Figure 3b) that appeared to be different in appearance to all the other examples of blue pigment from Amara West.

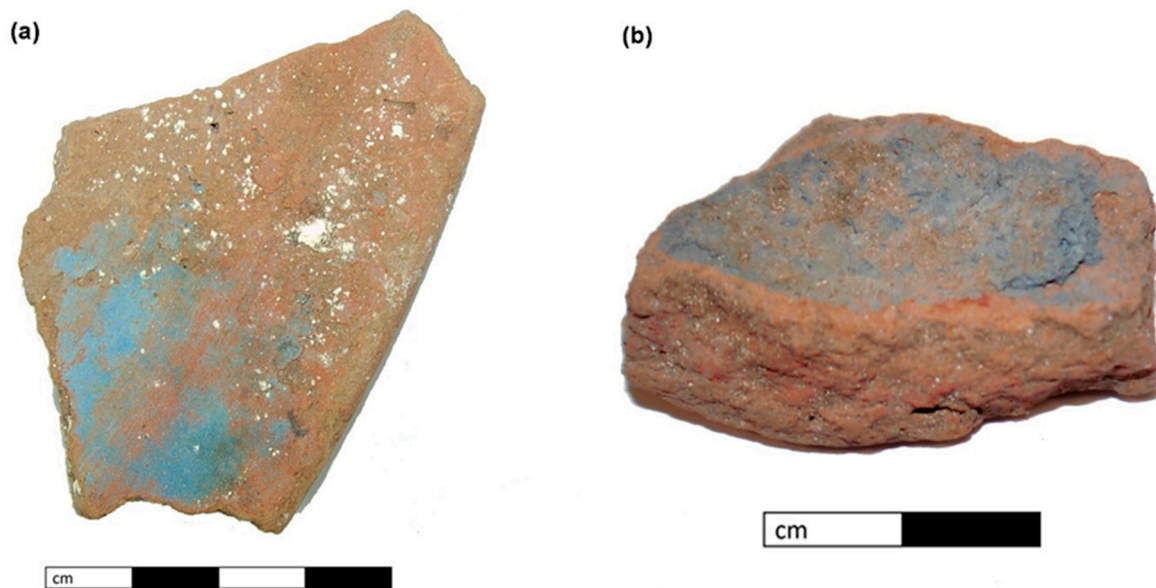


Figure 3. (a) Palette F6223 (PS140) from E13.29.2 (context 5224) with bright blue pigment (b) Palette F2644 (PS539) from D12.7.6 (context 12062) with greyish-blue pigment.

Finds of green pigments were uncommon at Amara West. A pale green pigment was found on three palettes (Figure 4), all from an early phase of the walled town E13 (Figure 2). A bright green pigment was found in minute quantities on a large grindstone from room E13.14.1, and as a pile of granules on the floor next to the grindstone. This material may originally have been held in a container made from an organic material such as leather, but organic materials are almost entirely absent in the archaeological record at Amara West. One further palette holding green pigment came from D11.7, a trench containing rubbish deposits in the Western Suburb.

2.2. Instrumentation and Analytical Techniques

All samples were examined using polarized light microscopy (PLM) [25]. Additionally, attenuated total reflection Fourier transform infrared spectroscopy (ATR-FTIR) was used to confirm identification in some cases [26]. Where elemental analysis was thought to be necessary, a scanning electron microscope (SEM) coupled with an energy-dispersive X-ray spectrometer (EDS) was used [27]. Powder X-ray diffraction (pXRD) was used to analyze the pale green pigment and the greyish-blue pigment [28]. Sub-samples taken from the palettes for the analyses are likely to have been heterogeneous due to the nature of the material. Multiple samples were taken for PLM and ATR-FTIR, and multiple regions were examined by SEM-EDS.



Figure 4. Pale green pigment on palette F6119 (PS126) from E13.31.2 (context 5331).

2.2.1. Polarized Light Microscopy (PLM)

A small sample of pigment was dispersed on a microscope slide in Meltmount™, with a refractive index of 1.662, and covered with a cover slip. Each sample was then observed in plane-polarized light and in crossed polarized light. More detail on the method is given by Easthaugh et al. [25]. One advantage of this technique is that it allows for the identification of the components in mixtures of pigments.

2.2.2. Attenuated Total Reflection Fourier Transform Infrared Spectroscopy (ATR-FTIR)

The instrument used was a Nicolet 6700, with a deuterated triglycine sulphate (DTGS) detector and a KBr beamsplitter. The spectra were run over the range 4000–550 cm^{-1} , and 32 scans were taken for each sample for both the background and the sample run. The resolution was 4 cm^{-1} , and the optical velocity was 0.6329. Before each sample was analyzed, a background analysis was run to remove the effects on the final spectrum of atmospheric water vapor and the internal components of the instrument. The spectra were compared with the spectra available from the Infrared and Raman Users Group's Spectral Database [29], submitted by various institutions, and with reference materials held at the British Museum.

2.2.3. Scanning Electron Microscope Energy-Dispersive X-ray Spectroscopy (SEM-EDS)

The instrument used was a Hitachi S-3400N fitted with an Oxford Instruments Inca Spectrometer, calibrated with a cobalt standard. The instrument was used at 20 kV, 120 s counting time, and 10 mm working distance. Both the full vacuum and variable pressure modes were used, this is indicated in the results. To prevent charge build up, a carbon coating was used. The probe current was 80–100 micro amps.

2.2.4. Powder X-ray Diffraction (pXRD)

The samples were hand-ground to a fine powder in an agate pestle and mortar. The powdered sample was then loaded into a Bruker zero height zero background (a polished silicon wafer) sample holder for analysis. pXRD analysis was performed using a Bruker D2

Phaser compact X-ray diffractometer located in the forensic laboratories of Anglia Ruskin University (Cambridge, UK). This instrument was fitted with a water-cooled 2.2 kW Cu anode X-ray tube operated at 300 W (30 kV, 10 mA), a Ni β -filter, and a Bruker LynxEye™ silicon strip position-sensitive detector (operated in θ -2 θ scan mode). The sample rotation was 15 r.p.m. and the step size (2θ) was 0.02° , with a nominal wavelength of 1.5402\AA . Scan range and integration time varied and are stated in the results for each sample. Interpretation of the results used MATCH! version 3.12 (www.crystalimpact.com, accessed on 16 September 2021) with the Crystallography Open Database data set version COD-inorg 14 January 2021 (www.crystallography.net/cod/, accessed on 16 September 2021).

3. Results

3.1. Blue Pigments

The seventeen bright blue samples were identified as Egyptian blue (Figure 3a). Egyptian blue can be identified using a combination of PLM (Figure 5) [25] (p. 26) and ATR-FTIR (Figure 6). An SEM-EDS analysis of the polished sections of blue pigment gave the atomic ratio of Ca:Cu:Si:O as 1:1:4:10, indicating that the material was calcium copper silicate $\text{CaCuSi}_4\text{O}_{10}$, a compound structurally and chemically analogous to the rare mineral phase cuprorivaite [30] (Table 1). In some cases, the Egyptian blue pigment had been mixed with gypsum or calcite, identified using PLM and ATR-FTIR (Table 2).

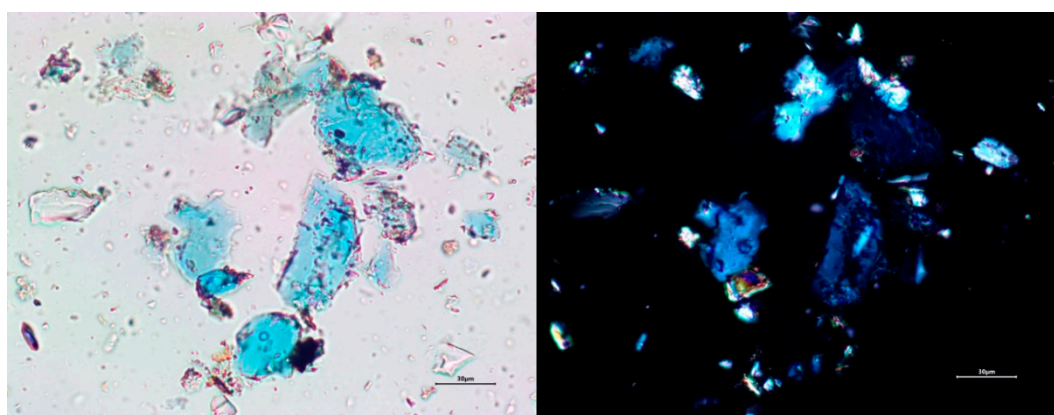


Figure 5. Dispersion of paint containing Egyptian blue from palette PS538 (F12423), seen under plane-polarized light (left) and crossed polarized light (right), both at $\times 400$. Scale bar shows $30\mu\text{m}$.

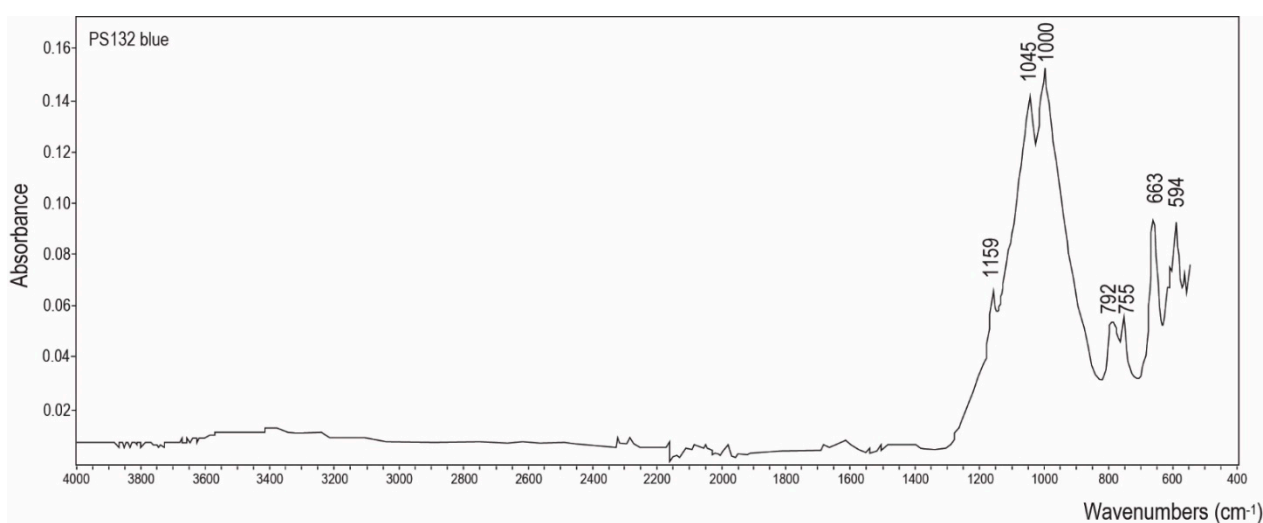


Figure 6. ATR-FTIR spectrum for blue paint from palette PS132 (F6147). Peaks indicate Egyptian blue [31].

Table 1. SEM-EDS analysis of Egyptian blue pigments from Amara West. These are the average results obtained for the samples PS317, PS304, PS305, PS394, PS316, and PS315, all mounted in polished resin blocks for analysis on full vacuum.

Element	Wt.% Oxide	Atomic%	Relative Standard Deviation	Ratio to Cu Atomic %
Si	67	25	0.66	4
Ca	14	6	1.26	1
Cu	19	6	2.01	1
O		63	0.67	10

Table 2. Results for samples of blue pigment from palettes.

Find Number	Sample Number	Building	Approx. Date BCE	Analysis	Mineral Identification
F2644	PS539	House D12.7.6 (context 12062), Western Suburb	1180–1000	PLM, ATR-FTIR, SEM-EDS, XRD	Blue earth (inc. clinocllore and riebeckite)
F15656	PS860	House D11.2.4 (context 2716), Western Suburb	1160–1000	PLM	Blue earth
F16667	PS865	Trench D11.7 (context 13569), Western Suburb	1300–1200	PLM, ATR-FTIR	Blue earth
F15193	PS893	House D12.8.8 (context 12891), Western Suburb	1160–1000	PLM, ATR-FTIR	Blue earth
F7569	PS287	Building E13.20.5 (context 10331), walled town	1200–1180	PLM	Egyptian blue
F7569	PS324	Building E13.20.5 (context 10331), walled town	1200–1180	PLM	Egyptian blue
F7684	PS537	Building E13.22.5 (context 10434), walled town	1210–1190	PLM	Egyptian blue, gypsum
F2600	PS540	Building E13.20.1 (context 10324), walled town	1200–1180	PLM	Egyptian blue
F6223	PS140	House E13.29.2 (context 5224), walled town	1190–1160	PLM, ATR-FTIR, SEM-EDS	Egyptian blue
F6264	PS417	House E13.29.2 (context 5261), walled town	1190–1160	PLM	Egyptian blue
F6223	PS438	House E13.7.12/E13.29.2 (context 5224), walled town	1210–1180	PLM	Egyptian blue, gypsum
F6190	PS431	Area E13.31.2 (context 5332), walled town	1200–1190	PLM	Egyptian blue
F6169	PS437	Area E13.31.1 (context 5352), walled town	c. 1200–1180	PLM	Egyptian blue
F6047	PS418	Area E13.29.1 (context 5219), walled town	c. 1180–1160	PLM	Egyptian blue
F6147	PS132	Area E13.29.4 [context 5325], walled town	c. 1200–1180	PLM, ATR-FTIR, SEM-EDS	Egyptian blue
F6474	PS443	Area E13.31.1 (context 5336), walled town	c. 1200–1180	PLM	Egyptian blue

Table 2. Cont.

Find Number	Sample Number	Building	Approx. Date BCE	Analysis	Mineral Identification
F6147	PS427	Area E13.29.4 (context 5325), walled town	1200–1180	PLM, ATR-FTIR	Egyptian blue, gypsum
F6170	PS127	House E13.6.4 (context 5341), walled town	1160–1140	PLM, ATR-FTIR	Egyptian blue, gypsum
F15193	PS893	House D12.8.8 (context 12891), Western Suburb	1160–1000	ATR-FTIR	Egyptian blue
F15020	PS534	House D12.8.7 (context 12840), Western Suburb	1160–1000	PLM	Egyptian blue
F12423	PS538	Open area D12.10 (context 12211), Western Suburb	1140–1000	PLM	Egyptian blue, calcite

The four palettes containing the greyish-blue pigment (Figure 3b) were examined by ATR-FTIR and PLM (Figure 7). The ATR-FTIR analysis was inconclusive. Under the polarizing microscope, elongate, prismatic, almost colorless low-relief particles with a refractive index slightly greater than the medium (Meltmount™, RI = 1.662) were observed. Their appearance is corroded, a process occurring over the geological timescale. In crossed polarized light, some particles had yellow-blue anomalous interference colors. This combination of properties suggests a degraded blue amphibole; a refractive index range of 1.680 to 1.706 is typical for riebeckite [32] (p. 261). The granite accessory minerals zircon and apatite were visible in PLM, as were quartz particles. A sample of the greyish blue pigment from palette PS539 analyzed by XRD was found to contain chlorite (variety clinocllore), and the blue-colored sodic amphibole riebeckite (Figure 8). The EDS analysis (Table 3) is broadly consistent with this composition, and this material is best characterized as a naturally occurring blue earth, being a heterogeneous mixture of minerals including chlorite and riebeckite.

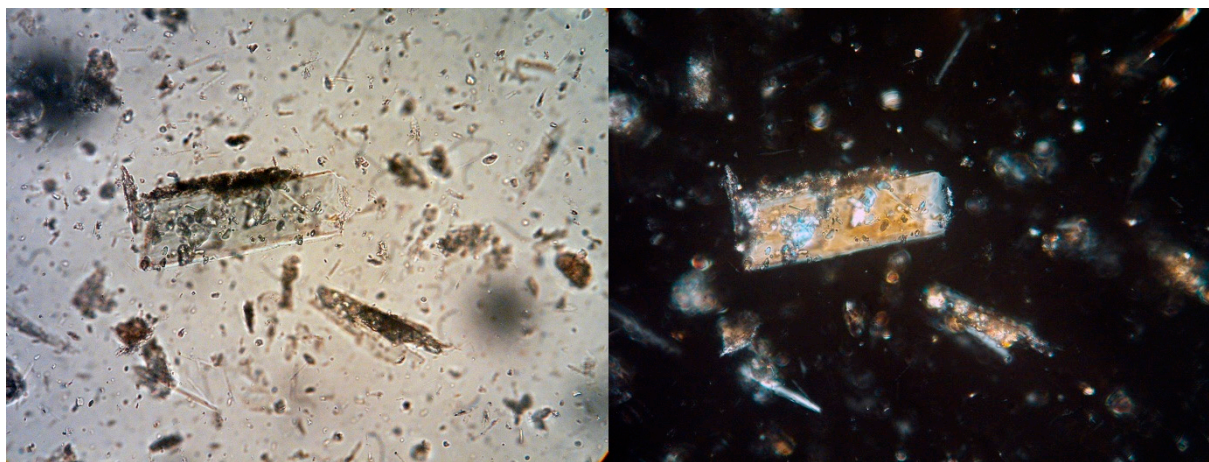


Figure 7. Dispersion of greyish blue pigment sample PS539 from palette F2644 in plane-polarized light (left) and crossed-polarized light (right) x400.

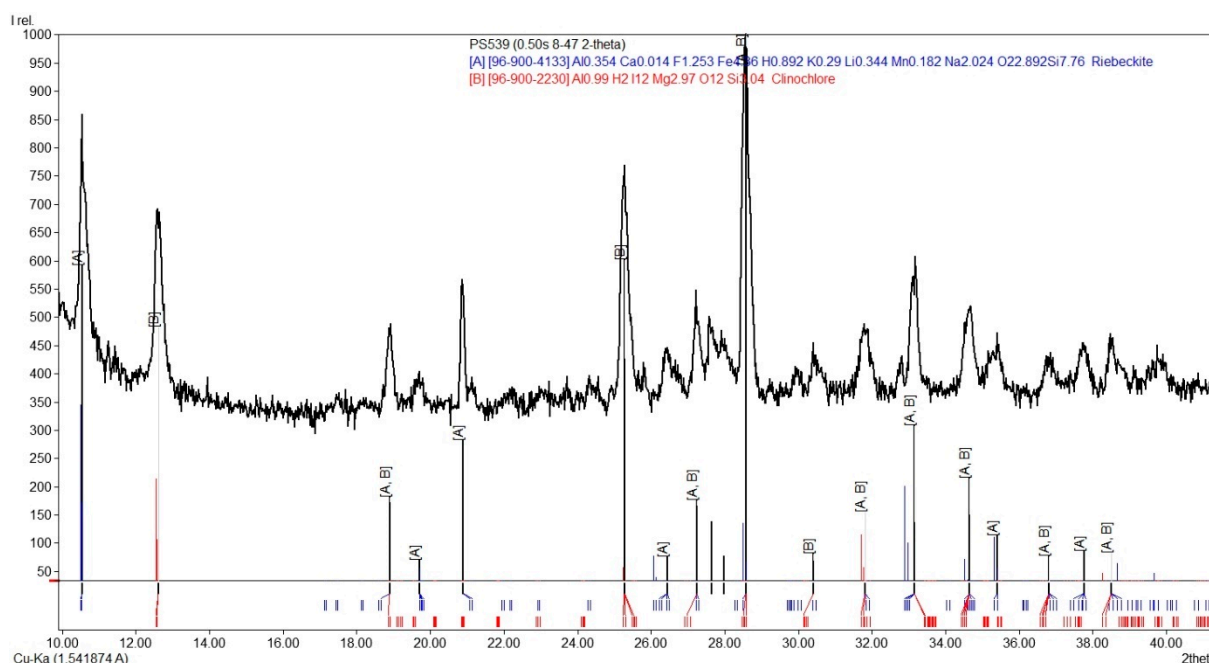


Figure 8. XRD results for sample PS539 from palette F2644 (Figure 3b). PS539 is a mixture of clinocllore (a chlorite, Crystallography Open Database (COD) entry 96-900-2230) and the blue sodic clinoamphibole riebeckite (COD entry 96-900-4133). The scan was from 8° to 47° 2θ (step size 0.2°), with an integration time of 0.50 s.

Table 3. SEM-EDS analysis of blue pigment PS539 in two areas of the palette using variable pressure; sample was analyzed directly from the object. All figures in wt.% oxide. ΣFeO = total Fe as FeO. n.d. = not detected.

Element	wt.% Oxide Region 1.	wt.% Oxide Region 2.
SiO ₂	37.2	27.2
Al ₂ O ₃	7.9	19.1
ΣFeO	16.5	25.1
MgO	11.4	14.8
CaO	7.3	n.d.
Na ₂ O	0.7	0.4
K ₂ O	0.4	0.1
TiO ₂	2.1	n.d.
MnO	0.3	n.d.
Cr ₂ O ₃	n.d.	0.4
Total as given	83.8	87.1

3.2. Green Pigments

Three different green pigments were identified from Amara West. The pale green pigment in the palettes was a mixture of calcite and chlorite, identified using PLM (Table 4). The chlorite particles displayed pale green to colorless pleochroism in polarized light and a typically anomalous blue under crossed polarized light [25] (p. 102) (Figure 9). No copper was detected by SEM-EDS (Table 5). Sample PS126 from palette F6119 (Figure 4) was analyzed by XRD and found to consist of the chlorite mineral penninite, calcite, quartz, and actinolite (Figure 10).

Table 4. Results for samples of green pigment from palettes, and pigment from grindstone and pile next to grindstone.

Find Number	Sample Number	Type of Object	Building	Approx. Date BCE	Analysis	Mineral Identification
F6119	PS126	Palette	Area E13.31.2 (context 5331), walled town	1200–1180	PLM, ATR-FTIR, SEM-EDS, XRD	Chlorite (penninite), amphibole (actinolite), quartz, calcite
F6463	PS248	Palette	Area E13.31.2 (context 5346), walled town	1200–1180	PLM, ATR-FTIR	Chlorite, amphibole, quartz, calcite
F6467	PS249	Palette	Area E13.31.2 (context 5334), walled town	1200–1180	PLM, ATR-FTIR	Chlorite, amphibole, quartz, calcite
F16767	PS869	Palette	Trench D11.7 (context 13568), Western Suburb	1300–1000	PLM, ATR-FTIR	Egyptian blue, yellow ochre, calcite
F6184	PS506	Grindstone	Magazine E13.14.1 (context 5361), walled town	1250–1210	PLM, ATR-FTIR, SEM-EDS	Copper trihydrox-ychloride
	PS118	Raw pigment on floor beside grindstone F6184	Magazine E13.14.1 (context 5365), walled town	1250–1210	PLM, ATR-FTIR, SEM-EDS	Copper trihydrox-ychloride

Table 5. SEM-EDS analysis of green crystals from sample PS126 from palette F6119 (unpolished, carbon coated). All figures in wt.% oxide.

Element	wt.% Oxide
SiO ₂	24.0
Al ₂ O ₃	16.4
ΣFeO	18.6
MgO	13.1
CaO	0.6
Na ₂ O	n.d.
K ₂ O	n.d.
TiO ₂	n.d.
MnO	0.3
Cr ₂ O ₃	n.d.
SO ₂	0.6
Total as given	73.6

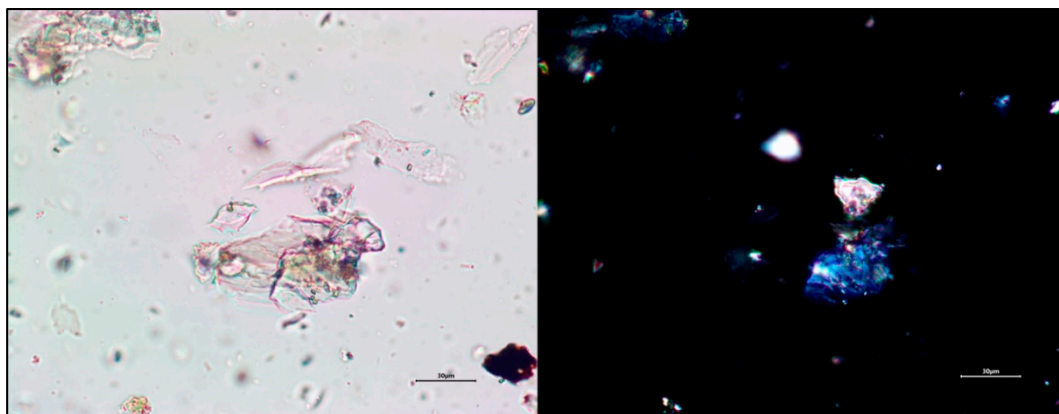


Figure 9. Dispersion of green pigment sample PS126 from palette F6119 in plane-polarized light (**left**) and crossed polarized light (**right**) x400. Pale green particles in polarized light show the anomalous blue interference colors typical of penninite in the crossed polarized image.

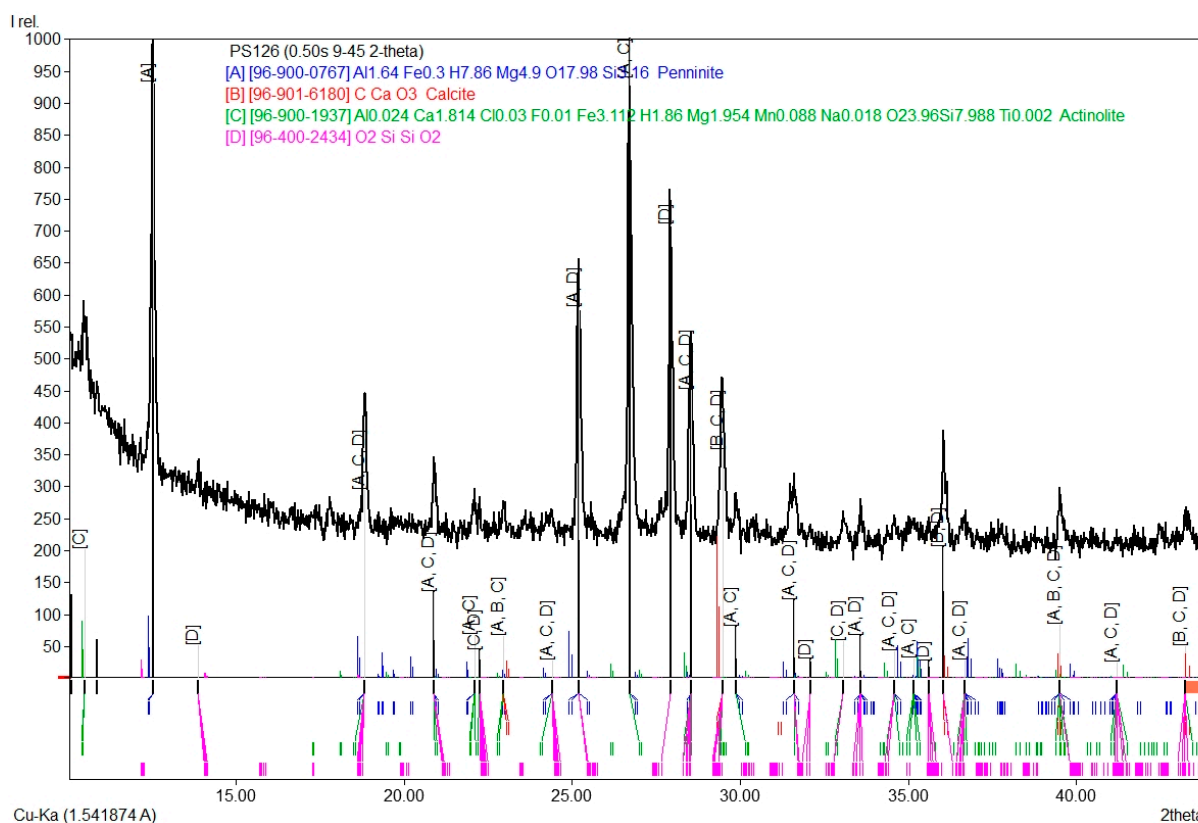


Figure 10. XRD results for sample PS126 from palette F6119 (Figure 3). The COD entries are: penninite 96-900-0787, calcite 96-901-6180, actinolite 96-900-1937, and quartz 96-400-2434. The scan was from 9° to 45° 2θ (step size 0.02°) with an integration time of 0.50 s.

The bright green pigment from the grindstone and the pile beside it were identified by PLM and ATR-FTIR, and confirmed elementally by SEM-EDS as a copper trihydroxy-chloride ($\text{Cu}_2\text{Cl}(\text{OH})_3$), henceforth CTHC, Figures 11 and 12). Mineralogically, CTHC is reported as either atacamite or paratacamite, but the methods used here cannot distinguish between these polymorphs.

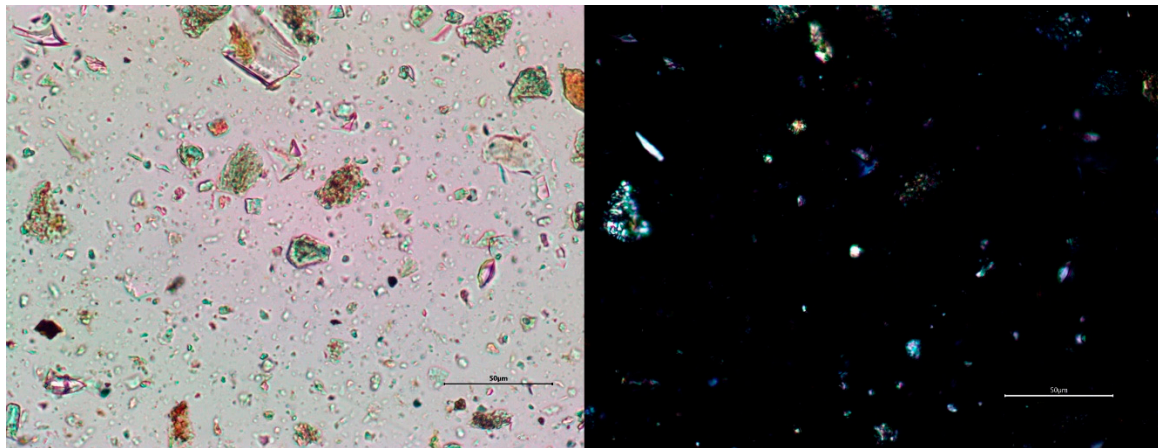


Figure 11. Dispersion of green pigment from pile in sand PS118 in plane-polarized light (**left**) and crossed polarized light (**right**) $\times 400$. Translucent green crystals with high relief in plane-polarized light and moderate birefringence suggest copper trihydroxychloride [25] (p. 61).

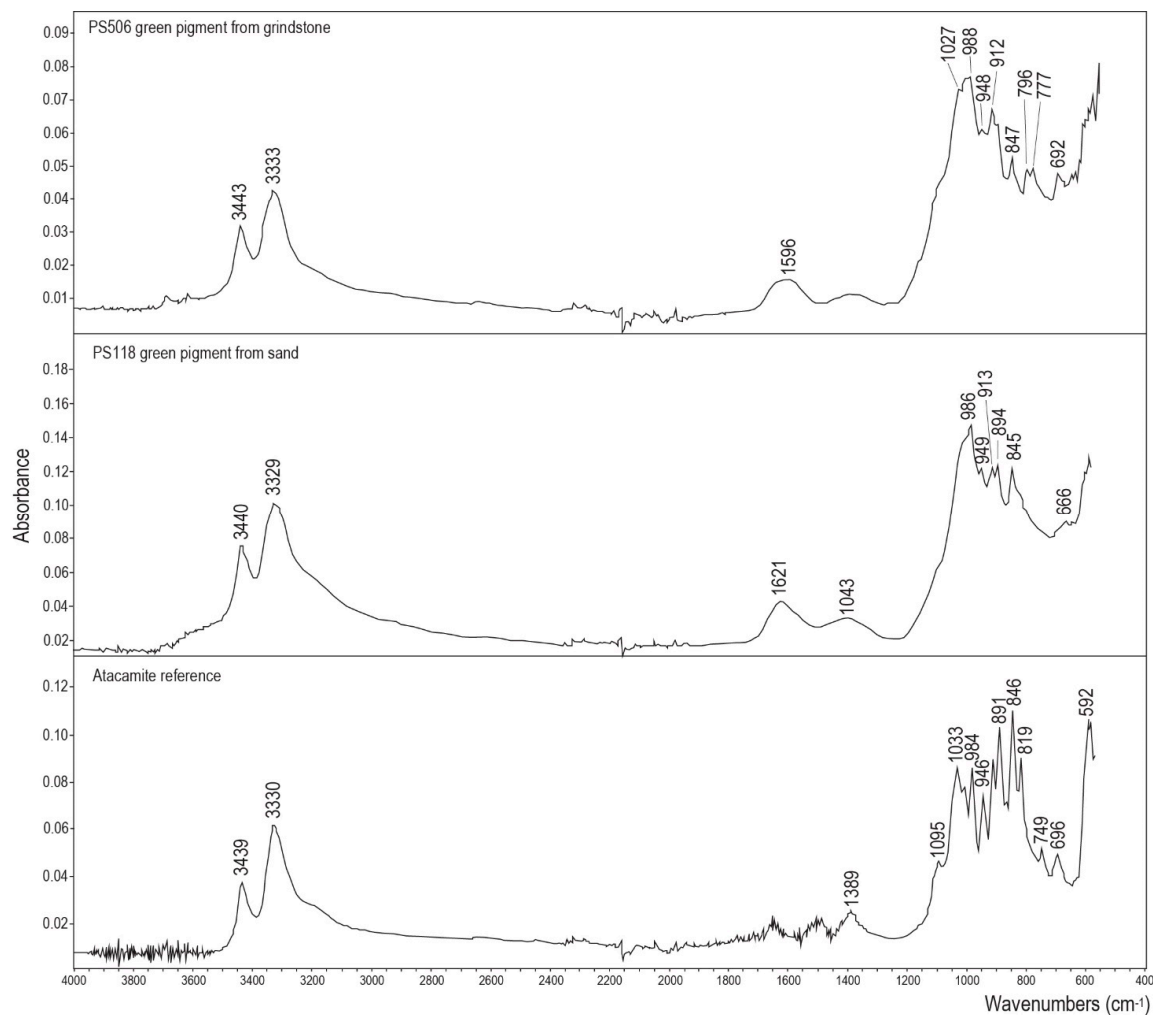


Figure 12. ATR-FTIR spectra for: green pigment from grindstone (PS506) (**upper part**), green pigment from floor next to grindstone (PS118) (**central part**), and reference atacamite pigment purchased from Kremer Pigmente (www.kremerpigmente.com, accessed on 16 September 2021) (**lower part**). Spectra for PS506 and PS118 are similar and accord well with peaks for the Kremer atacamite reference [33].

A third green pigment, from a palette in the Western Suburb (sample PS869 from palette F16767), was observed in PLM to be a mixture of yellow ochre (generically hydrous iron oxide) and Egyptian blue.

4. Discussion

Laboratory analyses of a range of pigment samples from Amara West indicated a broad alignment with contemporaneous practices in Egypt, with the use of red and yellow ochres, charcoal black, gypsum, and man-made Egyptian blue. However, a number of unusual blue and green pigments were identified. Four palettes found in the Western Suburb bore deposits of grey-blue pigments, comprising riebeckite-containing blue earths. The sodic amphibole solid-solution series glaucophane-riebeckite forms blue minerals. While the glaucophane end-member is restricted to blueschist facies metamorphic rocks, riebeckite occurs in alkaline igneous intrusive rocks, typically syenites and peralkaline granites; a granitoid origin for this pigment is thus suggested by the accessory minerals present. Riebeckite-bearing granites are known in Sudan in the Bayuda Desert just south of the 4th Cataract of the Nile, and also in Jebel Sabaloka at the 6th Cataract [34–36]. Archaeological remains of human activity are documented continuously in the Bayuda from the Palaeolithic to medieval times [37], and at Sabaloka from the Palaeolithic until the recent past [38]. Both areas lay outside the zone of direct control by the pharaonic state, although the trade of raw materials and worked goods from the south is well attested [39]. No examples of a blue riebeckite pigment have previously been reported from Egyptian contexts, although riebeckite granites can be found in Egypt [40]. Glaucophane pigments used alone or in combination with Egyptian blue were identified at Knossos and Thera, and may have been employed to eke out the brighter Egyptian blue pigment [41–43]. These results and interpretations remain tentative and require further study for confirmation, as recent pigment analyses of Minoan wall-paintings have only identified the presence of Egyptian Blue [44]. Experimental work by the authors has shown that glaucophane, which has identical properties to riebeckite once finely ground, produces a workable blue-grey colored pigment [25] (p. 105), which demonstrates that riebeckite is a reasonable choice for a pigment. We suggest that this mineral could have been collected from superficial deposits as a ‘blue earth’ associated with the erosion of these igneous rocks.

The vast majority of blues reported from Egypt, and the other 17 samples analyzed in this study, are Egyptian blue, a synthetic pigment that is known from Egypt from all Pharaonic periods [8,45]. Given the very small quantities of Egyptian blue found at Amara West, and the lack of evidence for the production of the pigment at the site, it seems likely that Egyptian blue was being imported to Amara West from Egypt. Unfortunately, the glass phase in the Egyptian blue from Amara West was too degraded to analyze for trace elements which might have indicated its geographical origin. If the manufacture of Egyptian blue was a state controlled process, as appears to be the case with glass [46,47], the people skilled in its creation would have been located at key centers for the royal court, around which production processes are likely to have nucleated, supported by the associated demand for temple and funerary decoration. When Amara West was occupied, Qantir in the northeastern Delta was one such possible production center where there is evidence for the production of Egyptian blue pigment [48]. If knowledge of the production of Egyptian blue was restricted, the availability of the pigment at sites far from the capital may have been limited. It is also possible that use of Egyptian blue was restricted to a certain segment of the population, either due to location (e.g., away from royal centers), or to societal restrictions based on status. All four instances of the blue earth pigment come from a late phase of the town, and may be a local adaptation due to a restriction on the use of Egyptian blue, perhaps due to a lack of material available, as it is possible that state supplies to pharaonic towns in Nubia waned in the later New Kingdom.

Three instances of the blue earth pigment come from the later phases of occupation (c.1180–1000 BCE), with the other from a context with no reliable dating evidence. The combination of the extramural location and relatively late date prompt consideration of

the changing nature of Amara West. As has been documented through other strands of evidence, for example in funerary architecture [21], an oval building constructed in the Nubian architectural tradition [49], or the forms of female clay figurines [50], it might be that indigenous (Nubian) expressions of material culture were becoming more visible and present within the town in its 100–150 years of occupation. Liminal spaces in colonial environments have been noted as sites of innovation [51], and both the concepts of hybridity and cultural entanglement [52] have informed frameworks for understanding the interplay of ideas, aesthetics, technologies, and worldviews in constructing identity in Nubia under colonial pharaonic rule. Was the use of blue earth pigment a reflection of persistent indigenous traditions in pigment use? Further identification and consideration of blue earth pigment use in both northern Sudan and Egypt would have to be undertaken to test the validity of such hypotheses.

Turning to the greens, a mixture of Egyptian blue and yellow ochre was found on a palette in the Western Suburb. Other examples of mixing yellow ochre with Egyptian blue to create a green pigment are known from Egypt, for example on the walls of the tomb of Amenhotep III c. 1349 BCE [5], and on a cartonnage fragments from the Ptolemaic or Roman Periods [53].

The green pigments found on a grindstone and nearby it on the ground were identified as a CTHC, a pigment that has been occasionally reported from elsewhere in ancient Egypt, on Middle Kingdom tomb reliefs from Deir el Bahri [54] and Deir el Bersheh [55], and in combination with Egyptian blue on unspecified objects [6]. A study of objects in the collection at the Louvre found CTHC on 4th/5th Dynasty (c.2600–2350 BCE) stone sculptures, and upon a 22nd Dynasty (c. 943–731 BCE) coffin and mummy case [7]. Some researchers have claimed that CTHC pigments are a result of the deterioration of glassy synthetic pigments due to their interaction with chloride ions [56,57]. In the occurrences reported here, the green pigment was found in a preparatory or discard context, not applied to the wall of a tomb or building. There was no evidence of any previous co-existing glassy phase, and there are multiple examples of the glass-bearing synthetic pigment Egyptian blue from the same area of the site that have significantly degraded glassy phases but which retain their bright blue color. It seems likely, therefore, that this example of CTHC pigment from Amara West was always a green copper pigment. It is possible that the green pigment was originally malachite (copper carbonate hydroxide $\text{Cu}_2\text{CO}_3(\text{OH})_2$) that has decomposed in a saline environment [53], however, the geology of this section of the Nile Valley is very different to the situation in Egypt, and the groundwater may have a lower salinity. The rarity of the atacamite (CTHC) mineral in nature has led scholars to suggest that the green CTHC pigment was manufactured in ancient times. Several medieval recipes for the manufacture of blue-green pigments from copper are known, the best known being that of Theophilus for *viride salsum*, or “salt green” [58]. His instructions produce various copper corrosion products, including green atacamite-type copper chloride [59].

The three pale green pigments were identified as having clinocllore, a variety of chlorite, as a major phase. Chlorite-bearing pigments are often included in the loose group term “green earths” [60,61] (pp. 394–400). Green earths have only rarely been identified in ancient Egyptian contexts. A green earth pigment containing glauconite was identified on lime plasters at the royal palace of Amenhotep III (c. 1330 BCE) at Malqata [14]. Green earth pigments containing celadonite and glauconite were also reported on one piece of cartonnage from the Third Intermediate Period c. 850 BCE and from one piece of cartonnage from the late Ptolemaic or early Roman Period (c. 30 BCE) [62,63]. Green earth has also been identified on a 2nd century CE Roman Egyptian shrine in the Dakhleh Oasis [64]. Given how frequently green earth pigments were employed by other cultures, it seems strange how little they are apparently encountered in ancient Egypt. In situ elemental analytical methods would be at risk of under-identifying clay and related pigments since they do not have metal ions that would distinguish them from the substrate. It is possible that green and blue earths have been under-reported because they are more likely to be encountered in contexts (e.g., houses) that are less commonly studied in detail.

The analysis of pigment traces from carefully excavated urban contexts at Amara West reveals how the town's inhabitants turned to unusual pigments to supplement the more common array of materials used in the Nile Valley at this period. Only with further laboratory analysis of samples from urban contexts across northern Sudan and Egypt will it be possible to better understand if the use of these green and blue earths was more widespread than we currently appreciate based on the elite and mostly funerary objects in museum collections. An expanded range of analyses may also elucidate the role of indigenous and/or regional traditions in prompting divergences from the typical pigment palette.

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